Experiments Demonstrating an Electrical Effect in Vibrating Metals.

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In a previous communication* some experiments were described by one of us which indicated the possibility that part of the energy of a vibrating wire gave rise to an E.M.F. in it, and so produced an alternating current strong enough to be audible in an ordinary telephone, and but little affected by the angle of the wire to the lines of the earth's magnetic force.

2. Among other questions raised at the discussion of the paper was one whether the E.M.F. might not be due to a thermal effect at the soldered junctions of the vibrating wire. The effect of rusting the wire and also the possibility of mechanical transmission of the vibration to the telephone were also mentioned. To endeavour to throw further light on what appeared to be a rather obscure effect, the experiments have been continued, and have led to a further development of the matter.

3. The previous communication, referred to above, stated that wires as short as 9 inches in length had given good response when subjected to vibrations. We reduced this length by steps to $\frac{1}{2}$ inch of vibrating wire, in the form of a bridge, and also of a spring fixed at one end only, the circuit being completed by a very fine slack wire soldered to the free end; with these similar effects were obtained, using specimens of various materials. Thus, within ordinary working limits the length of the wire has no important effect on the results obtained.

Effect of Rusting the Wire.

4. To try more definitely than formerly the effect of rusting the wire, we fitted up identically two equal lengths of fine piano steel wire taken from the same coil. They were mounted 1 foot apart on a rigid oak panel, and were stretched nearly vertically down from a firm insulated support, and, passing over the edge of a wooden bridge, were kept in tension by weights of 2 lb., which were increased to 4 lb. when the wires were being tested. The slack ends of the steel wires were soldered to flexible leads and taken to the recording instruments.

These wires were each 60 inches in length, of which 39 inches were used

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for the tests of vibration, viz., that part between the upper support and the bridge. The resistance of each circuit as fitted was 3·55 ohms, their frequency of vibration was 183 with a 2 lb. and 205 with a 4-lb. weight to stretch them. The only apparent difference between them was that the bridge was not exactly parallel to the panel, owing to a difficulty in fitting it in place, and consequently the distances of the wires from the panel were 3 inches and 3½ inches instead of being equal.

After preliminary trials to decide on the routine method of comparing the results produced by their vibration, one wire was dosed with dilute sulphuric acid and the other one coated with vaseline to preserve its brightness, and the wires are referred to as "rusting" and "bright" respectively.

5. The tests were commenced on June 23, 1918, and were carried out every few days till the rusting wire broke on August 3, after 36 days' treatment.

The tests were as follows: First, they were joined up direct to an ordinary P.O. telephone in a distant room, and it was at first found that the response from both wires was equally good when they were plucked; this was also the case with the telephones of the amplifier.

The amplifier telephones were replaced by a rectifier of zincite-tellurium, in circuit with a sensitive (non-reflecting) galvanometer (150 ohms). On subjecting the wires to vibration the currents generated thereby caused deflections on the galvanometer, which were taken as being approximately proportional to the E.M.F. generated, if no adjustments were changed. The deflections were, however, affected by the adjustments of the amplifier and of the rectifier, also by the tension of the wires and the frequency of their vibrations. As the recording instruments were required for other work, their adjustments could not conveniently remain unaltered, and direct readings of the galvanometer from day to day could not be uniformly constant for the same deflections, we therefore decided to take the bright wire, and the results it gave on each occasion of testing as a standard, and compare the results given by the rusting wire by the percentage of their respective deflections.

A considerable number of trials were necessary to obtain uniformity in the plucking of the wires and uniform readings of the galvanometer for the same plucks of the same wire. These resulted in choosing 4 lb. as the tension and three positions on the wires for applying the pluck at 1 inch, 14 inches, and 33 inches below the point of support. At the upper position the finger was used to pluck the wires, and the maximum vibration possible imparted to them; for the other two positions, a hard bone rod, with notches at the right places, was used, and found to give very uniform results

for each pluck. The means of at least three deflections were taken, but if these differed by more than 1 in 10, more were taken. There were, however, very few abnormal deflections recorded, and these few easily accounted for and remedied at the time, *e.g.*, the loosening of a screw securing the bridge, a little too much friction at the bridge of the rusting wire remedied by oil.

6. The results of these observations are plotted in fig. 1, and they show a sharp fall in the proportional deflections from the rusting wire from the commencement of the tests for 15 days, when unfortunately the bone plucker was accidentally broken. Although a replica was made, it was not so uniform in the results it obtained as the original one, from both wires; but we see no reason for doubting the results it recorded being a good representation of the proportional effects of the wires; telephonic checks, repeatedly carried out, confirm them, and it was very noticeable during the last 10 days of the tests that the rusting wire was losing elasticity, uniformity, and response, and a change in its pitch and timbre was very noticeable to the plucker.

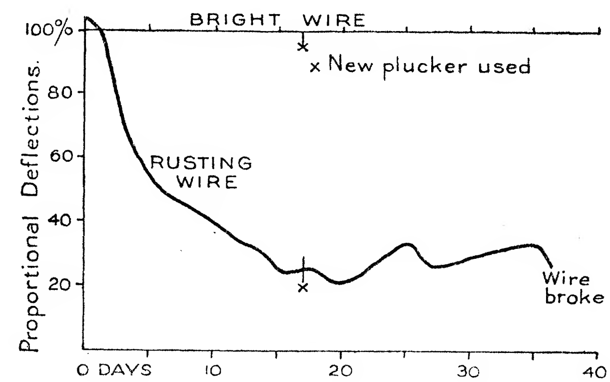

Fig. 1.

The curve, however, shows a tendency for its response to fluctuate between the 16th and 36th day, when it broke at the part to which it would be subjected to the greatest angular displacement when under test, just below its point of support. It was then being plucked at the middle position. The fracture was at once examined under a microscope, and showed the wire to be eaten away uniformly for about two-thirds of its diameter, a fine thread of steel remaining bright, with a fibrous fracture.

Equal lengths, 33 inches, of the vibrating parts of the two wires were then balanced, and it was found that the rusting portion had 4 per cent. greater resistance than the bright portion. An intermediate test of the complete circuits on the 12th day had shown a 3 per cent. increase.

The rusted wire at positions not close to the point of fracture had only suffered a slight reduction in its cross-sectional area.

7. The inductive effect of one wire on the other was repeatedly tried, and it was noticed during the last week of the tests, that the vibrating effect of the rusting wire, compared with the bright one, was markedly less in the telephone. In these tests the non-vibrating wire formed the receiving inductive circuit, and was connected to the amplifier telephones. The response was partly due to mechanical resonance between the wires, for when their tension and pitch were different, the notes due to both were heard, but t was also electrical, for if the circuit of the vibrating wire was open, the sound in the telephones was much weaker than when it was closed.

8. It can be deduced from these experiments that rusting the surface of a wire does decrease the electrical effect produced by its vibration in a greater degree than can be attributed solely to the increase of its resistance by reason of the decrease in its cross-sectional area.

The Effect of Vibrating Metallic Bodies.

9. The previous paper cited described various methods by which the stretched wire was subjected to vibrations and the effects they produced in the telephone. Occasionally, the slack ends of the wires, in mountings in which the wire was short, had been joined up to the primary winding of suitable induction coils, and their secondary windings taken to the telephone. Good response had been obtained with no voltage added to the circuit.

This indicated a means of eliminating all chances of the effect being due to thermal or other causes at soldered junctions, or to bad contacts in the vibrating circuit.

A ring 2 inches wide was cut off from the end of a seamless non-magnetic nickel alloy tube, 1·1 inches in diameter, 0·05 inch thick. The ring was encircled with a coil, 12 ohms resistance, with $\frac{1}{4}$ inch air space, the ends of the coil being taken to the amplifier and its telephones. On tapping the ring loud response was obtained in the telephone, and this was not lost when the ring was slit longitudinally, or when its dimensions were reduced to a narrow strip of curved metal.

This experiment opened up a wider field of research than did the vibrating wires, though the effect is attributed to the same cause.

Trials with larger masses of metal were then made, the tube from which the ring had been removed being the first piece tested. It was now 2 feet long, and apparently of uniform section and good workmanship and material for its whole length.

It was hung vertically through the coil fixed to a wall, and it was then

tapped near its centre by a swinging pendulum attached to a projection at its upper end. The tube could be raised or lowered at will without changing the strength of the blow of the pendulum. The energy absorbed was $\frac{1}{4}$ ft.-lb. at each tap, approximately.

The intensity of the sound in the telephone varied greatly as the position of the encircling coil along the axis of the tube was changed by raising or lowering it. At some positions no sound was heard, at others it was extremely loud and plainly audible in a telephone without any amplifier.

Subsequently, a zincite-tellurium rectifier with the galvanometer and also a thermo-galvanometer, which would record steady currents of 0·01 milliampère, were used to record the effects.

11. Many tests with different tubes and rods of various materials have been carried out under these conditions, but the tube now under consideration is one of the most interesting examples, on account of the lack of symmetry found in the positions of maximum currents recorded at equal distances on each side of its centre. It was found that the results did not depend on the manner or the position of its suspension, or on the spot on which it was tapped. After the first test, 6 inches were cut off from one end, but this did not greatly change the shape of the curve. Six inches were now cut off from the other end, when the curve became quite symmetrical. A bad flaw in the metal was found in the end just removed close to the cut. Somewhat similar results have been obtained with other tubes of non-uniform distribution of material in their construction, the curves got from them showing peaks or dips when the encircling coil is near these positions.

12. A seamless copper tube of uniform construction has consistently showed good symmetry on each side of its centre under the same general conditions of testing, but with many variations in their details. It is 36 inches long, 0·75 inch diameter, 0·1 inch thick. A coil fitting lightly on the tube was generally used, and this was slid inch by inch along it, and the results obtained on tapping it near the centre were recorded. These were checked by other coils and also by the telephone, with and without the amplifier. The fundamental note of this tube is 216, but the octave, 432 is predominant.

Fig. 2 shows the curve obtained of the varying circumferential currents; it will be seen that there are six peaks of maximum current, and that these are at the extreme ends and nearly equally spaced between the ends, and that there are dips indicating weak currents at the centre and between each peak. Other tubes tested give different characteristics, but in most cases there are signs of comparatively strong currents at the extreme ends. In this tube the deflections obtained at 14 inches and 21 inches are large but irregular, indicating positions of instability. Between the peaks a weak

longitudinal current has been traced by the use of a coil of special winding; telephonic checks confirmed this, the strongest response being got at places where the circumferential currents were weakest, viz., at 5 inches and 31 inches. Mechanical vibrations of the tube, indicated by sand, appeared greatest at places of minimum circumferential currents, at 10 to 12 inches, 17 to 19 inches, and 24 to 26 inches, but they were also very marked at the extreme ends.

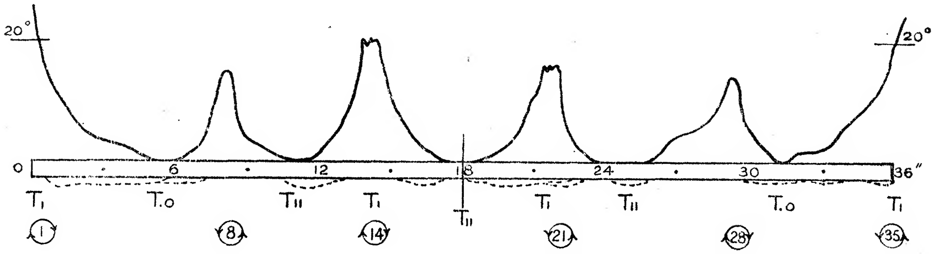

Fig. 2.—Curve showing deflections of a galvanometer, with rectifier, using a coil encircling a copper tube at various positions and tapping the tube near its centre. Deflections indicate the proportional strengths of the circumferential currents in the tube. T_0, T_1, T_{11}, show positions of nil, strong, and weak sounds, in a telephone connected direct to the coil, respectively. The numbers encircled indicate the approximate phases of the currents. Dotted lines below the axis of the tube indicate longitudinal currents observed. The tube was of seamless copper, 36 inches long, suspended horizontally. Numbers show the distance in inches from the end.

Previous tests with other tubes showed that the phases of the circumferential currents were not the same at all positions along the tube. This was investigated by using two coils singly and then joined in series, first in conjunction and then in opposition; one was fixed at some definite position on the tube, and the other one moved by steps along it, the deflections on tapping were taken and then analysed. With the copper tube, the analysis showed without any doubt that the circumferential currents were approximately opposite in phase at adjacent positions of maximum intensity, so that if the current at 1 inch was clockwise, it would be anti-clockwise at 8, 21, and 35 inches, and clockwise at 14 and 28 inches from end 1 inch. See fig. 2.

Response, but only in the telephone, has also been obtained from this tube and also from rods of various materials and sections when subjected to longitudinal vibrations by stroking with a resined leather. Encircling coils and searching coils held near the test piece were used, and also putting it in the circuit as if it were a wire. The results show that each tube has its own characteristic curve which may be much affected by the position of its points of support.

13. The tests with metals in a rod or tubular form led up to trials with other shapes, and it was found that the effect was obtainable in any metallic body tried, whatever its material or shape, when a coil of suitable shape and winding connected to the amplifier was used, and if it were placed round or near to the vibrating body. The intensity of the effect, however, is very variable, not only with different materials and shapes, but also with the position and the angle at which the searching coil is held with reference to the test piece.

A nickel rod, slightly magnetic, has given the strongest response to light taps of any article tested, but steel is nearly as responsive. Lead and molybdenum appear to be the least so. Good response has been got from electric light carbons.

Non-metallic bodies in the form of rods, tubes, bowls, plates, etc., have been systematically tested, and, excepting carbon, have given absolutely no response under tests similar to those used with conductors.

14. When metal plates are mounted and bowed so as to vibrate at their natural frequency, such as Chladni plates, the electrical effect produced in suitable coils near the plate is much greater than when they are only subjected to tapping. The zones in which the currents are strongest can be mapped out, and many tests of this nature have been carried out. Of the materials tried in this form, thin tinned iron and steel give by far the strongest effect: copper, brass, and aluminium seem about equal. The higher the frequency of vibration the smaller is the zone in which the effect can be detected, and stronger is the response. These currents can be detected when the vibrating plate is a part of the electrical circuit, but the intensity is weaker than that obtained by searching coils held near the plate.

With high frequency large deflections can be obtained with the thermo-galvanometer through the amplifier, and that the vibration of the searching coil is not the cause has been very carefully tested; non-conducting plates, equally efficient as Chladni vibrators, giving no response whatever with coils of suitable winding and rigidly mounted.

Some of these experiments are described below, in paragraph 17, and the results obtained are shown in figs. 3 and 4.

Cause of the Effect.

15. The original experiments carried out with a steel wire vibrating in the line of the earth's magnetic force had given almost negative results, and had led to the conclusion that the earth's magnetism was not the primary cause of the effect.

However, it became increasingly evident as these experiments progressed

that magnetic bodies consistently gave stronger electrical effects than non-magnetic bodies under the same conditions of testing.

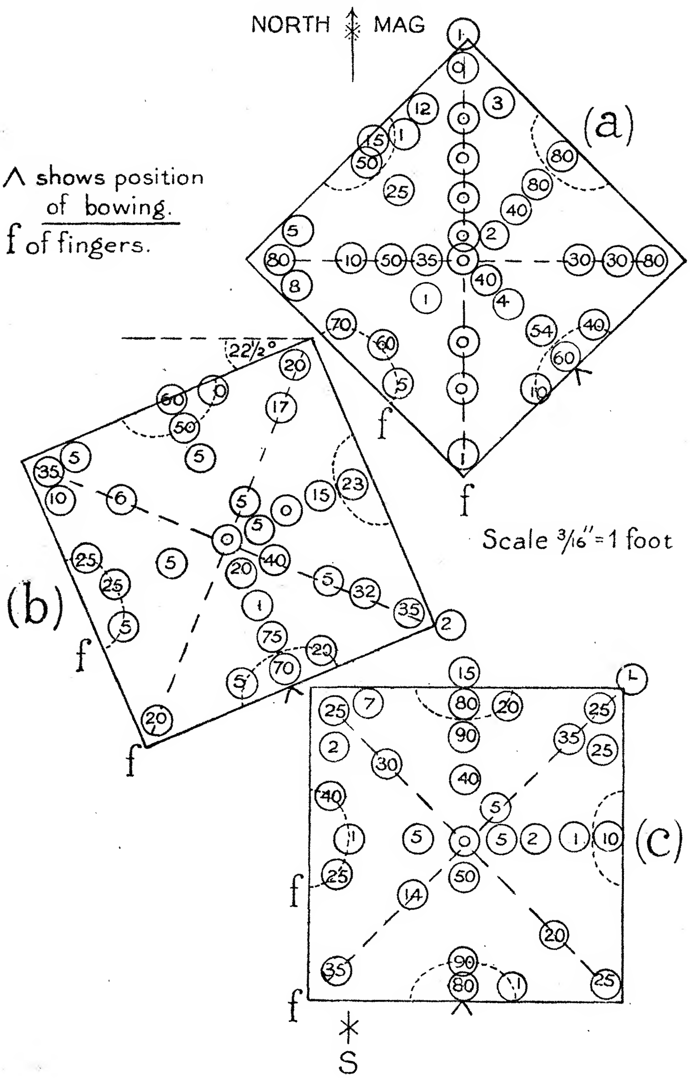

FIG. 3.—Vibrating Chladni Plate, 12 inches square.
(25) indicates positions of searching coil and deflections of thermo-galvanometer.

It appeared necessary to further examine the reason for this difference, and a very long series of tests have been carried out with this object, and also to ascertain the amount of error, if any, which might be caused by the vibration of the body under test being imparted to the searching coils mechanically through its support or through the air.

The following is a short description of some typical experiments in this connection :—

Vibrating wires, tubes, rods, and plates of steel and copper which were

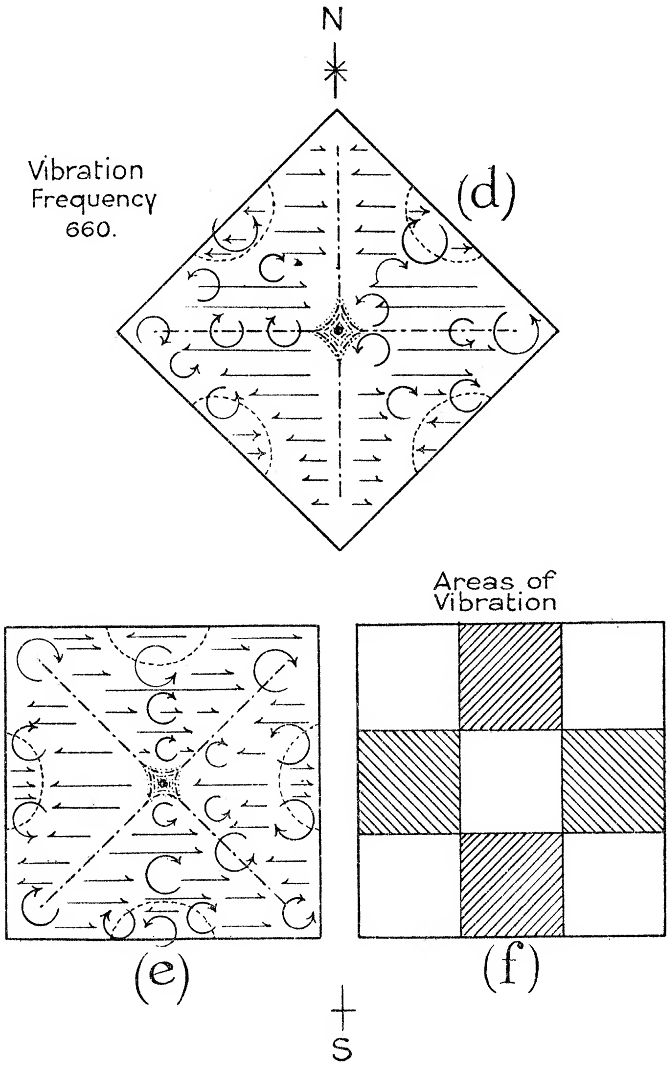

FIG. 3 (*continued*).

Probable circulation of currents. Broken lines show sand pattern.

giving electrical response were subjected to sudden changes in the strength of the magnetic field in which they were vibrating. In all cases the intensity of the effect was greatly increased by a strengthening of the field, but the proportionate increase was less with steel than with copper.

The curve in fig. 2 for the copper tube was altered in its characteristic

shape when a bar magnet was brought near the tube; the maximum effect was greatly increased at positions of the coil encircling the tube near the positions in which the field due to the magnet was strongest.

Vibration frequency 950.

Data as in fig. 3.

Frequency 500.

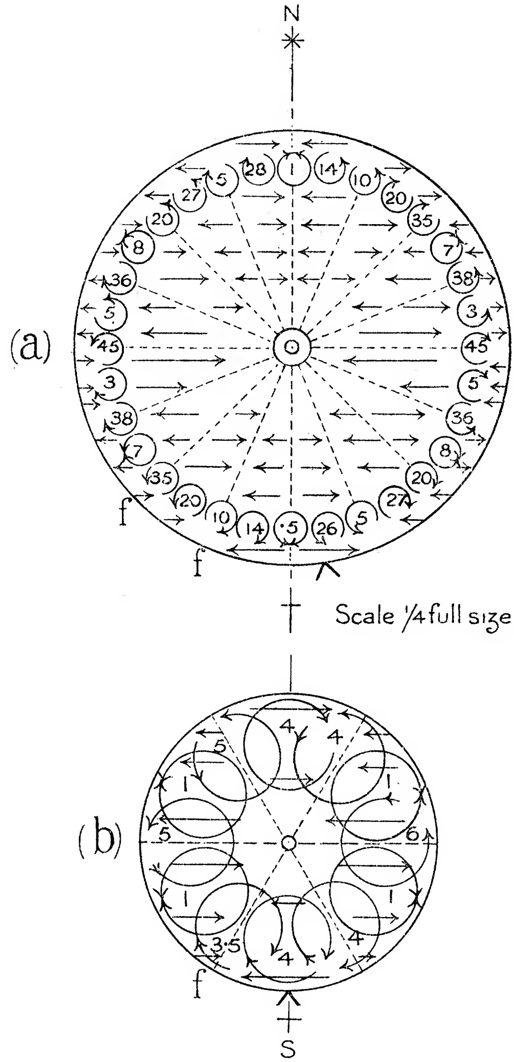

Fig. 4.—Circular Plates.

When this tube was suspended in the line of the earth's magnetic force (the dip line), the curve, though not changed in form, was of much less amplitude, response being obtained in the amplifier telephones only.

These rough tests left no doubt that the primary cause of the electrical effect was due to the conducting body vibrating in the earth's magnetic field,

cutting lines of force, and so generating an alternating current of electricity in the body.

It was considered that the best proof of this theory would be the measurement of the currents produced in fields of known magnetic intensity, and that this could be best effected by varying the inclination of a vibrating wire or plate in the earth's field.

It was found by preliminary trials that a thermo-galvanometer, fitted to the amplifier in lieu of the telephones, was sensitive enough to record the currents produced in a short wire bridge when subjected to vibrations by bowing. The bridge was mounted in a strong rigid ebonite holder, and those used were 2–8 inches in length between the points of support. Tension of the wire was adjustable by means of a bone screw; the ends of the bridge were connected by slack conducting wires to the ends of a low resistance primary winding of a transformer, the high resistance secondary of which led to the recording instrument, viz., thermo-galvanometer, or telephone, through the amplifier, or direct to the telephones.

In order to be able to readily increase or neutralise the magnetic field round the bridge when so desired, a two-coil tangent galvanometer was used in some of the experiments. The bridge holder was fitted to this in the exact position of the usual compass needle.

The galvanometer was secured to the hinged flap of a table, so that it could be turned through or fixed at any angle between the horizontal and vertical with its axial line in the magnetic meridian.

The necessary circuit for neutralising the earth's field was fitted. By reversing the battery poles the earth's total field could be doubled in strength when the axis of the galvanometer and the wire bridge were in the dip line.

The middle of a large class room was selected for the position of the apparatus, and the dip angle and the line of the magnetic meridian were carefully measured and laid off. All portable magnetic bodies were removed from the vicinity. The dip angle was found to be 67°. The apparatus was then mounted on the flap, so that the wire bridge occupied the exact position of the dipping needle when the observation was made.

When the battery was connected to the galvanometer circuit to neutralise the earth's magnetic field, a small compass needle in the place of the bridge was observed to have lost all directive power.

Thus, we had a bridge in a position where the magnetic field, if not absolutely nil, was extremely weak, and we had a means of quickly increasing it to the earth's field and of doubling this by altering the battery connections.

Numerous bridges were tested in this apparatus, and their results were consistent though different in their intensity.

Without exception, all gave stronger response when inclined at a considerable angle to the line of the earth's magnetic force, than when at a small angle to it.

The curves shown in fig. 5 are typical examples. It will be seen that the response did not vanish when the bridges were in the dip line, and that it was greater with steel than with copper. When the earth's field was neutralised, there was still an indication on the thermo-galvanometer that response was obtained, and, as regards the steel wire, as far as could be judged by the telephone, the response was but little affected by doubling or neutralising the field or leaving it normal. The 36-inch copper tube under tests of the same nature gave similar results to those got from the copper wire bridge.

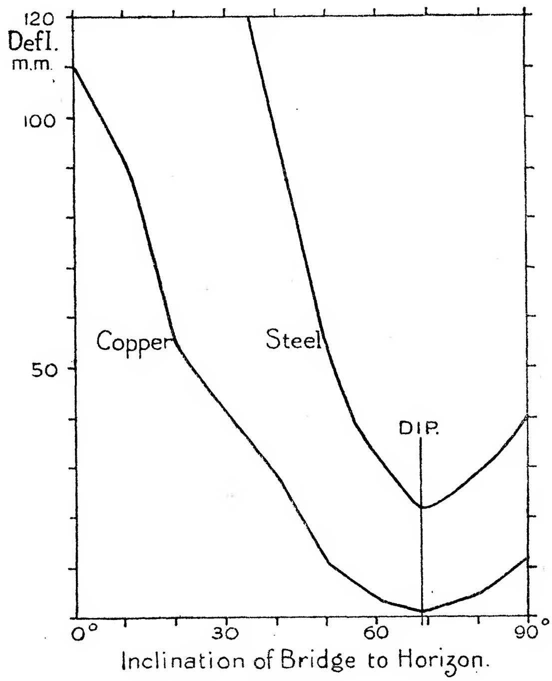

Fig. 5.

With fine wires of platinum, platinoid, and copper the same results were obtained, but the response was fainter.

With a stout bar bridge of copper, comparatively insensitive in all positions, no response could be obtained in the dip line with the earth's field neutralised.

With steel and platinoid wires the slightest scraping of the wire in any

direction could be plainly heard in the amplifier telephones under all conditions above mentioned.

To lessen any chance of mechanical vibration of the galvanometer frame or mounting being imparted to the coil, it was held in the hand, although no response could ever be obtained in the telephone when any part of the apparatus except the actual bridge was tapped or bowed.

16. Some other tests were as follows :—

A plate, 6 inches by 4 inches, of electrolytically pure copper was used as a Chladni plate and sustained in free vibration by a non-magnetic tapper, whose ebonite hammer struck it lightly normal to its under surface. The plate was fixed on its mounting at an angle of 67° from the vertical, so that it could easily be placed with its face normal to the lines of the earth's magnetic force. Tests showed that the maximum electrical effect with a coil, 1-inch diameter, was obtained opposite an adjacent corner to that struck by the tapper, and could be got at a distance of 2 inches when the face of the plate was normal to the lines of force. The plate and tapper mounted on an oak base were placed on the base-plate of an air-pump, and rested on a layer of felt and a coil of indiarubber tubing, being kept firmly in position by means of a leaden weight. The glass dome of the air-pump was placed over them, and the coil fixed outside the dome 2 inches from the corner of the plate. Response to the tapping was obtained, the air pressure inside the dome was reduced to 0·4 inch mercury, with no change in the intensity of the response. Air was then quickly admitted, no change being noticeable. When, however, the face of the plate was moved away from the normal to the lines of force, the intensity of the response increased. A brass plate of identical dimensions to this one gave the same results.

Experiments of a very similar nature were carried out with a piece of the nickel alloy tube mentioned in paragraph 9, and its response was strong enough to be recordable with the thermo-galvanometer. The deflections obtained, in 0·5 inch pressure, with varying distances of the coil from the glass dome of the air-pump are as follows :—

Tube in dip line.	Distance.	Tube at 60° to dip.
40	1″	70
6	1·5	8
1·5	6	2·5
0	10	1

In the amplifier telephones, response was obtained at 60° up to a distance of 45 inches. This tube was replaced by a glass one of nearly similar dimensions. No response whatever could be got from it under any conditions.

Very slight response with full amplification has been obtained from a glass tube and a glass bowl (using a low resistance coil of light and flimsy construction), when vibrating strongly at their natural frequency; this necessitates careful testing in delicate experiments for this possible error, a test invariably carried out in the experiments herein described.

A copper bowl and a glass tumbler of nearly similar shape and musical pitch were mounted together on a stand, one on each side of the tapper, which struck them alternately and produced a good acoustical response from both of them in the open. They were placed under the dome of the air-pump and pressure was reduced to 0·5 inch, when no sound was audible to the naked ears. Good electrical response was obtained in the telephones from the copper bowl, none whatever from the glass tumbler; there was no change in the results when the air was again admitted into the dome.

Many other tests of a like nature have been carried out, and the only difference ever noticed between full and reduced air pressure was with a thin tinned-iron plate, with which the response was greater with reduced pressure, probably owing to its vibrations being less damped in the rarer air.

Experiments have also been carried out with the searching coils inside the dome of the air-pump, and the vibrating test piece outside it, and these showed no difference in the response from a change in the air pressure.

Carbon filament glow lamps have been tried as searching coils and given fair results, in spite of their unsuitability from the point of view of electrical efficiency as such; they show, however, that air vibration is not a prime factor in causing the effects described. Nor is the prime cause due to the alternating field in the locality, which is often a disturbing influence in the telephonic reception when using the amplifier. This has been tested by carrying out some of the experiments at places far away from any electrical installation, with no apparent effect on the response produced.

Experiments with Chladni Plates.

17. The numerous tests with these vibrating plates, carried out to ascertain if any rule could be found regulating the circulation of the currents generated in them, for a long time led to no definite conclusion. The effects were frequently very strong, though often inconsistent, but they indicated that the maximum current effect was to be obtained with the searching coils over the nodes of vibration which are shown by the sand ridges on the vibrating plate. The plates had not been placed in any particular direction with respect to the earth's magnetic field. It was decided to test the effect of the earth's horizontal force on a horizontal vibrating plate, with reference to its influence on currents circulating near the sand ridges.

The results obtained were remarkable, and showed without doubt that the prime cause of the effect is due to the vibration of the metal in the earth's field, and that the generation of the currents thereby is not irregular or indefinable, but apparently follows a fixed law.

Amongst others, a square and a circular plate of brass, 12 inches across, have been tested systematically. Some of the results with them are shown in figs. 3 and 4.

The square plate was fixed first with one of its diagonals in the magnetic meridian. The searching coil generally used was $1\frac{1}{4}$ inches in diameter, rigidly mounted and capable of being fixed with $\frac{1}{2}$-inch air space, over any part of the surface of the plate. It was wound with 900 turns of 32 S.W.G., resistance 67 ohms; the ends of the coil were taken to the amplifier and deflections obtained through it were recorded on a thermo-galvanometer.

The plate was bowed to obtain the pattern indicated in the diagram until it gave out a loud pure tone, and the deflections noted when the bow was off the plate. The adjustments were kept constant during the tests. The deflections recorded in some of the positions explored are shown in fig. 3, *a*, *b*, *c*.

When sufficient data had been obtained on this line of the diagonal, it was turned through an angle of $22\frac{1}{2}°$, and the observations repeated, and then through another $22\frac{1}{2}°$, so that two of the plate's edges were in the magnetic meridian, and the same process gone through. It will be seen from fig. 3, *d* and *e*, that the nodes lay along the diagonals with loop nodes in the middle of each side.

With a diagonal node in the magnetic meridian, it will be seen from fig. 3, *a*, that the deflections obtained along this line were very small or nil; but that they were large along the node normal to the meridian. A close inspection of the loop nodes shows that here the deflections are also less when the coil is over any part of any node lying near the line of the meridian, than when over a part making an angle with it.

On rotating the plate through $22\frac{1}{2}°$ and $45°$, it can be seen from the diagrams that the actual deflections over any part of the plate (except the centre where no deflections have ever been obtained) are all changed, increasing as the angle of the node to the meridian increases, and *vice versâ*. The plate, indeed, acts somewhat like a magnetic compass, *e.g.*, rotating it through $45°$ has increased the deflection at two of its corners from 1 to 25, and reduced it at the two other corners from 80 to 25, and none of the deflections recorded at any part of the plate remain the same, except at the centre.

When the surface of the plate was fixed in the dip line and the tests repeated, the deflections increased as much as 50 per cent.

By means of two similar coils placed over different positions on the plate, joined alternately in conjunction and opposition, the relative phases of the currents, if any, can readily be detected; the results obtained by these means are included in the diagrams.

The circular plates required rather a different treatment, and were used to test the accuracy of a theory formulated by the results obtained from the square plate.

The nodal lines may be considered to be stationary compared with the other parts of the vibrating plate; the movement of these surfaces, up and down, cut the horizontal component of the earth's magnetic field, and thereby generate an E.M.F. along lines normal to the meridian. The direction of the current thus generated along any line at a given moment depends on the direction of motion of that part of the plate in which it lies, and will be reversed as the motion of the plate reverses. Thus, an alternating current may be set up in the metallic plate.

As the direction of the mechanical motion of the plate is opposite on each side of any nodal line at any moment, any currents generated will also tend to be in opposite directions, and there will be a tendency for them to circulate round a nodal line; there will also be the same tendency in such positions as may have a weaker E.M.F. at one side than the other, and such spots may be expected where the direction of adjacent nodal lines are not parallel to each other or to the meridian.

The intensity of these current eddies will generally be greater when they are formed by two opposing E.M.Fs. than when they are only to the differential effect of two unequal ones of the same sign. There may also be spots where no current is circulating, and also likely to be unstable in this respect, if the mechanical vibration of the plate is not absolutely uniform at each stroke of the bow, or if the position of its application changes.

The diagrams indicate the probable direction of the lines along which this E.M.F. is generated, and the circles show the actual results obtained, which fully confirm the theory outlined above. The tests of the circular plates seemed to put the question of its truth beyond any doubt.

In fig. 4, *a*, a 16-starred figure with a node in the meridian was explored, and gave consistent readings except at the four spots situated $57\frac{1}{2}°$ from the meridian, where occasionally the deflections were very small or nil, and where the phase differences were difficult to determine. The readings shown in the figure are marked 7 and 8, as they formed part of the series then being taken.

In fig. 4, *b*, a smaller plate was used, and a 6-starred figure with an antinode in the meridian explored. The results of the readings and phase

differences fully confirm the theory of the circulation of the currents, and also that they are not always confined to a small area, as the coil used in this test was a larger one than that used in fig. 4, *a*, being three-eighths of the diameter of the plate.

The above results were confirmed by using a single P.O. telephone joined direct to the searching coil. It was found that at spots in which any deflections had been recorded on the thermo-galvanometer with the amplifier, response was clear in the telephone, and that its intensity increased as the coil was moved over any spot where the deflections had been greater, and *vice versâ*.

Summary.

The results obtained by vibrating two steel wires, of equal length and under similar conditions of test, show that the electric currents generated in them by their motion in the earth's magnetic field are affected by the condition of the surface of the wires, a rusting of the surface causing a decrease in the intensity of the current compared with that in the wire protected from rust. This decrease is not wholly attributable to the increase in the electrical resistance of the wire due to its decreased sectional area.

The vibration of metallic bodies, of which many various forms and materials have been tested, generates electric currents in them which can be detected by their inductive action on searching coils connected to delicate recording apparatus.

Vibrating metals, and also carbon, in the form of rods or tubes, generate circumferential currents, which may vary in strength and phase at different positions along the axis of body, irrespective of its angle with the lines of force in an uniform magnetic field, so far as the characteristic curve of distribution along the axis is concerned. The strength of the currents, however, depends (primarily) on the angle of the axis with the lines of force, being greater when its inclination is greater, and *vice versâ*. When fixed in such a position that induced current in the vibrating metal from this cause would not be expected, the effect is very frequently not entirely eliminated.

Vibrating plates give similar effects if the nodal lines of mechanical vibration are regarded as axes of the vibrating body. The prime cause of this effect is due to the motion of the conductor in the earth's magnetic field, but there is a residual effect not yet accounted for.

Vibrating non-conductors do not produce this electrical effect.